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OBSERVED TURBULENCE INTENSITIES IN A DESERT BOUNDARY LAYER

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DISCLAIMER

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1. INTRODUCTION

A number of applied problems in atmospheric dispersion require the prediction of vertical and lateral turbulence intensities near the ground as a function of the local atmospheric stability. We have investigated σ_w/u_* over a wide range of stabilities at two desert sites in Nevada and California. The study was part of a meteorological baseline for field tests of atmospheric dispersion during liquified natural gas (LNG) spills. The data collected at Frenchman Flat (Nevada Test Site) during neutral and stable cases seem to be remarkably different from those of other published studies and lead us to hypothesize that, under certain conditions, different semi-empirical approaches would be required to predict turbulence intensities.

2. THEORY

The relationship between vertical turbulence intensity, σ_w/u_*, and Monin-Obukhov stability parameter, z/L, is generally agreed to approach the free-convection limit:

$$\sigma_w/u_* \approx A(-z/L)^{1/3} \quad -z/L >> 0 \quad . \tag{1}$$

For example, Panofsky et al. (1977) have surveyed a number of field studies and derived an empirical expression meeting both the condition of Eq. (1) and a consensus of neutral and stable results that show:

$$\sigma_w/u_* \approx 1.3 \quad z/L \geq 0 \quad . \tag{2}$$

Binkowski (1979) has developed a semi-empirical method for obtaining second moment closure to the turbulent energy equation yielding a predictive formulation for σ_w/u_* as a function of z/L, which has the same essential properties of (1) and (2). This result agreed with field data from Kansas and Minnesota. From this and other efforts to effect closure of the turbulent energy equations (Herbert and Panhans, 1979, Panhans and Herbert, 1979), it becomes evident that the success of the σ_w/u_* prediction rides on the success of relating the scaled momentum parameter ϕ_m to z/L, where

$$\phi_m = (kz/u_*)\ du/dz \quad . \tag{3}$$

On the other hand there is less likely a unique dependence of lateral turbulence intensity, σ_v/u_*, upon z/L. This may be due in part to the influence of the depth of the mixed layer (Panofsky et al., 1977) on σ_v/u_*.

3. EXPERIMENTAL OBSERVATIONS

At Frenchman Flat on the Nevada Test Site a 62 meter meteorological tower was instrumented with vertical propellor anemometers, sensitive wind vanes and cup anemometers, and aspirated thermistors. Each of these were scanned once a second with RMS and averages determined every three minutes by a microprocessor-based data acquisition system. The data of September-November 1979 were analyzed to determine u_* and L from profile measurements between 3 and 10 meter heights, while σ_w and σ_v data from each of two levels were averaged.

Data representative of the 5.5 height above ground showed features unlike other studies (Figure 1). We eliminated from the analysis periods when sensors would be near their thresholds ($u < 1.5$ m/s), and because of the wealth of data (n = 1925) chose to plot only the medians and upper and lower quartiles for each z/L value. We observed a steep gradient of σ_w/u_* near neutral stability rather than an approach to the expected constant of Eq. 2. We also observed much lower turbulence intensities under stable conditions than commonly reported. The distinguishing features of this site are an extremely small surface roughness ($z_o \approx 10^{-5}$ m) and a homogeneous upwind fetch for 3 km due to the flat playa. Since care was taken with the observations and analysis, we believe that what we have observed is a natural effect of the surface roughness and the lack of influence of mesoscale, organized flows during stable conditions. The characterisitic eddy structure may be expressed by the ratio σ_v/σ_w. We found that σ_v and σ_w were highly correlated (r = 0.9) regardless of z/L, giving confidence that the sensors were not anomalous since σ_v and σ_w are measured by separate devices.

A value $\sigma_v/\sigma_w = 4.1$ was observed at Frenchman Flat which was high compared to a value of 2.4 observed by us over rougher surfaces in a desert at China Lake, Naval Weapons Center, California. A value of 1.5 has been reported for rougher surfaces under neutral conditions (Binkowsky, 1979). We believe that the large value of σ_v/σ_w at Frenchman Flat indicates a reduced magnitude of σ_w relative to σ_v due to decreased roughness. Thus under certain conditions, better parameterization is required.

On the other hand, our data agree very well with Eq. 1 (A = 2.1) and also agree with the results of Binkowski for unstable conditions.

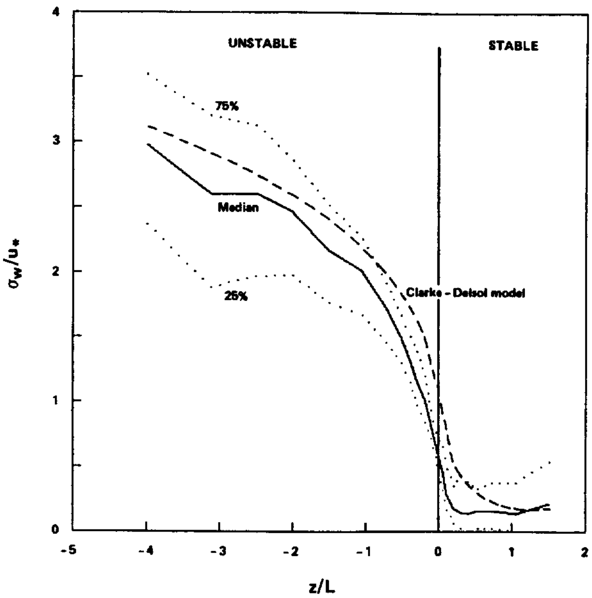

Figure 1. Vertical turbulence intensity versus atmospheric stability for 1925 samples at Frenchman Flat (Sept-Oct, 1979); solid line is median value, dotted lines are first and third quartiles, and dashed line is predicted value from Clarke-Delsol model.

4. DISCUSSION

We have found that semi-empirical predictive formulas which fit data over rougher surfaces and predict higher turbulent intensities for neutral and stable cases (Eq. 2) must be rejected for the smooth desert. However, based upon the hypothesis that a Prandtl-type closure condition would define the characteristic scale and consequently σ_w/u_*, we assume:

$$\sigma_w/u_* \sim u_* /kz(du/kz) \tag{4}$$

where k is Karman's constant. From Eq. 3:

$$\sigma_w/u_* \sim 1/\phi_m \tag{5}$$

Following Herbert and Panhans (1979), we choose the Clarke-Delsol parameterizations:

$$\phi_m = (1 - 15\ z/L)^{-11/40} \qquad z/L \leq 0 \tag{6a}$$

$$\phi_m = (1 + 5\ z/L)/(1 + \alpha z/L + 5\alpha (z/L)^2) \qquad 0\leq z/L\leq 1 \tag{6b}$$

$$\phi_m = 6/(1 + 6\alpha z/L) \qquad z/L\geq 1 \tag{6c}$$

where $\alpha = 0.0079$.

The results of predicting σ_w/u_* by (5) and (6) are shown in Figure 1. Much better agreement in the neutral and stable case is obtained.

5. ACKNOWLEDGMENTS

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